AD-761 098

HELIUM BUBBLE SURVEY OF PARACHUTE OPENING FLOWFIELD

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Army Natick Laboratories
Natick, Massachusetts

May 1973

TECHNICAL REPORT

[illegible]

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by

Paul C. Klimas

U. S. Naval Academy

Annapolis, Maryland

Project Order [illegible] 72-191

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Airdrop Engineering Laboratory

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) US Army Natick Laboratories Nat!ck, Massachusetts 01760	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

HELIUM BUBBLE SURVEY OF A PARACHUTE OPENING FLOWFIELD

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Paul C. Klimas

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
Dec 72	25	2

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	TR 73-48-AD
c. Project Order AMXRED 72-191	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	US Naval Academy Annapolis, Maryla d

13. ABSTRACT

A velocity survey of the flow field surrounding an 18 inch nominal diameter flat circular parachute model was made using the helium bubble technique. Due to asymmetrical model behavior arising from optical limitations, only two points in the filling cycle were examined. The point at which the canopy first reaches full open (instant at which inflation is complete) and at a time late in the cycle when steady state flow conditions are reached. Bubble streaks were photographed by two synchronized, orthogonally mounted still cameras, and the particle velocities were calculated using the measured lengths of the images and the camera exposure times. Although the canopy geometries at the two points considered were quite similar, their surrounding flow fields were not. At the instant of full inflation, both the axial and radial velocities reached much higher values than in the steady state operation and were confined to a region much closer to the canopy. Additionally the turbulent wake area near the vent was roughly only 40% as large as the steady state counterpart, and it had associated with it an average negative velocity equal to approximately one half the free-stream value. This is consistent with the over-inflation always noted for times immediately beyond full inflation. The large differences between the two flows about geometrically similar bodies indicate that the idea of obtaining opening field data using a series of rigid models which represent various phases of the opening geometry is innacurate.

(continued on attached).

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Feasibility	8					
Measurement	8					
Flow distribution	9					
Opening	9					
Parachutes	9					
Helium	10					
Bubbles	10					
Photography	10					

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Project Reference
1F1 62203 AA33

May 73

AIRDROP ENGINEERING LABORATORY
US ARMY NATICK LABORATORIES
NATICK, MASSACHUSETTS

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FOREWARD

This work was performed at the US Naval Academy for the US Army Natick Laboratories under Project Order AMXRED 72-191. This effort is part of a continuing program to develop and advance the state-of-the-art in airdrop technology.

This particular task was aimed at developing a better experimental technique for exploring the basic phenomenon associated with the flow field around inflating parachutes. The results of this experiment indicate that the helium bubble technique is well suited for studies of parachute flow fields.

The Project Officer for this work was Mr. James F. Falcone, of the Airdrop Engineering Laboratory.

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ABSTRACT

A velocity survey of the flow field surrounding an 18 inch nominal diameter flat circular parachute model was made using the helium bubble technique. Due to asymmetrical model behavior arising from optical limitations, only two points in the filling cycle were examined. The point at which the canopy first reaches full open (instant at which inflation is complete) and at a time late in the cycle when steady state flow conditions are reached. Bubble streaks were photographed by two synchronized, orthogonally mounted still cameras, and the particle velocities were calculated using the measured lengths of the images and the camera exposure times. Although the canopy geometries at the two points considered were quite similar, their surrounding flow fields were not. At the instant of full inflation, both the axial and radial velocites reached much higher values than in the steady state operation and were confined to a region much closer to the canopy. Additionally, the turbulent wake area near the vent was roughly only 40% as large as the steady state counterpart, and it has associated with it an average negative velocity equal to approximately one half the free-stream value. This is consistent with the overinflation always noted for times immediately beyond full inflation. The large differences between the two flows about geometrically similar bodies indicate that the idea of obtaining opening field data using s series of rigid models which represent various phases of the opening geometry is innacurate.

The flow field study demonstrated the ability of the helium bubble technique to collect previously unobtainable information.

1. Introduction:

Knowledge of the flowfield surrounding a parachute, particularly during the opening, is essential to any understanding of parachute dynamics. This fundamental information, however, has yet to be completely determined. The lack of valid data is due principally to the nature of the measuring devices which have been employed. They either physically obstruct the flow or opening due to their size (pressure rake, anemometer), or cannot function in regions of high fluid rotation (pressure rake, anemometer, smoke) such as are found in wakes and mouth regions. A system which has none of these disadvantages is one which introduces neutrally buoyant, highly visible and durable particles into the stream. One such devices was used by Pounder[1] in 1956 to measure steady flows about various canopies. This was done by generating helium-filled soap bubbles which were inserted into the air passing the parachute. The neutrally buoyant bubbles were dynamically indistinquishable from the air surrounding them, and their high reflectivity made them easy to photograph. The current investigation extends the use of this concept to ascertain the velocities during a portion of the opening process.

2. Apparatus:

The investigation was conducted in the United States Naval Academy 3 1/2 by 4 1/2 foot subsonic wind tunnel. The particular parachute model used was an 18 gore, 18 inch nominal diameter flat circular type having a 1.8 inch diameter vent.* Tunnel blockage limited the nominal diameter to this value. The model was constructed of 1.1 ounce rip-stop nylon, MIL-C-7020, Type I, having a permeability of 114 ft^3/ft^2/min. The suspension lines were 18 inches long and were tied to a 15/16 inch diameter steel ring. The model deployment system consisted of a 3 inch diameter, 12 inch long streamlined aluminum tube mounted along the tunnel centerline into which the parachute was loosely packed. Deployment was initiated by raising a solenoid driven pin which allowed a dead-fall weight to extract the parachute from the tube. The model then rode along a 5 foot long, 0.25 inch diameter aluminum rod to a point where the moving stream began the inflation. The rod served the dual purposes of stabilizing the motion and, since it was graduated into one inch intervals, of providing a length scale. This apparatus is shown in Figures 1 and 2. In steady operation the suspension line ring was located some six inches downstream of the deployment tube.

*This model was graciously supplied by Mr. William Ludtke of the US Naval Ordnance Laboratory, Silver Spring, Maryland.

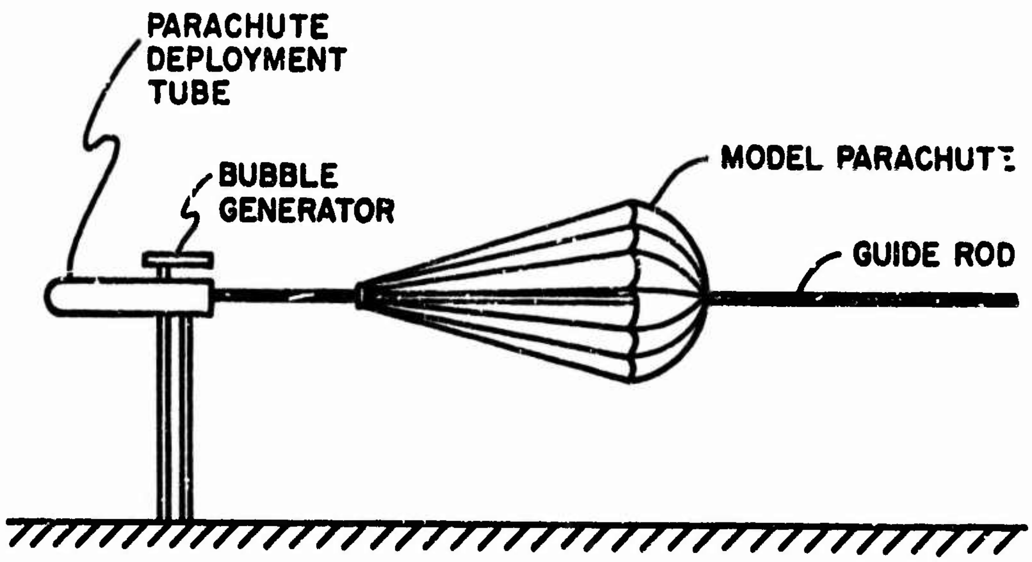
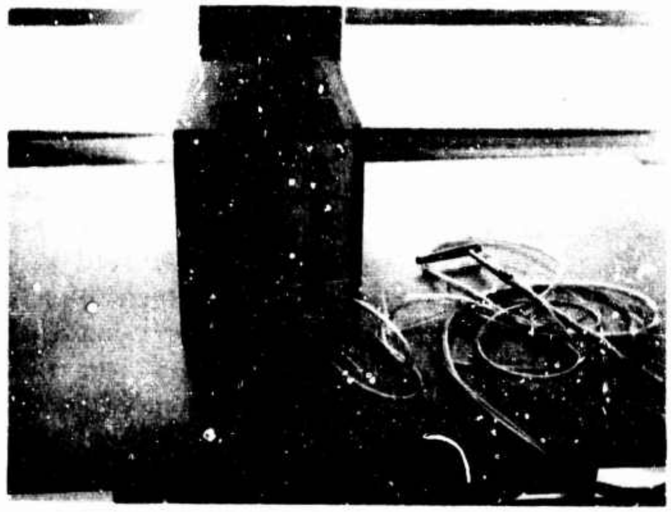
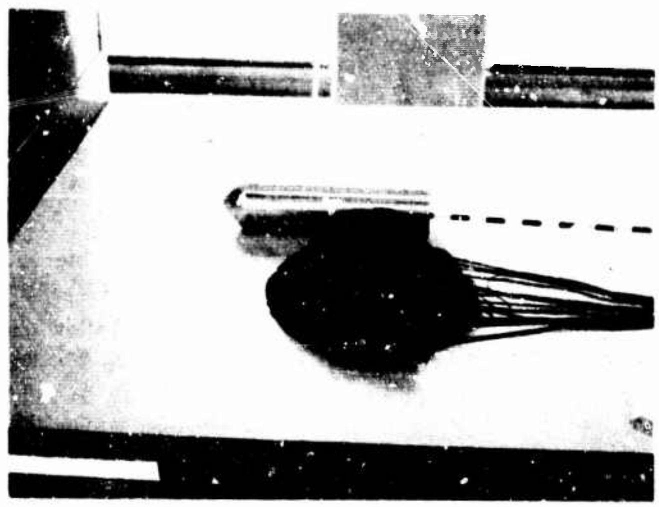


FIGURE I–SCHEMATIC DIAGRAM OF TEST APPARATUS



BUBBLE GENERATING HEAD AND CONSOLE



PARACHUTE MODEL AND DEPLOYMENT TUBE

Figure 2. Test Apparatus

The flow visualization technique centered around the bubble generating system shown in Figure 2.* Helium filled soap bubbles were formed in the pitot tube appearing device and broken off by high pressure air. The density of t' bubbles is within two percent of the density of air. Simultaneous photographs were taken by two still cameras mounted at right angles to each other and located 72 inches off the tunnel centerline. ASA 3000 speed film was used and illumination was provided by a high intesnity Xenon arc lamp mounted upstream of the test section and somewhat off axis. Although this presented the possibility of some disturbance to the freestream, it was necessary to sufficiently illuminate the upstream flow. The tunnel test section and the model were blackened to reduce glare and improve contrast.

3. <u>Experiment</u>:

The original experimental plan was to take a large number of photographs at each of four or five different fractions of the filling time. The dimensionless filling time (T), as defined below, is utilized to facilitate data analysis and interpretation:

$$T = \frac{t}{t_f}$$

where: t = instantaneous time

t_f = filling time (instant at which canopy first reaches full open shape)

Each set of photographs would include a number of randomly placed streaks. This would provide a description of the particle velocities over the full range of opening times. However, it was found that in order to get well defined streak photographs, that the bubble residence time needed to be that corresponding to a freestream velocity of approximately 10 ft/sec. Horizontal parachute operation, particularly during opening, at these low speeds gave a ratio of aerodynamic to static forces which rendered the opening asymmetrical. It was not until the process had progressed to approximately $T \simeq 1$ that the lack of symmetry became small enough to be considered negligible. For these times and those beyond, the differences in the maximum radii between the upper and lower portions of the canopy were less than seven percent of the average of these two extremes.

The tunnel speed was set at 8.5 ft/sec. A series of streak photographs taken with the model undeployed gave a tunnel axial velocity of 8.36 ft/sec, a radial velocity of 0.26 ft/sec, and a circumferential velocity of 0.51 ft/sec. Errors of the magnitude of the last two values would be expected in locating streaks made by the 0.125 inch diameter bubbles and exposure times used here. These streak images were sufficiently intense to be easily read.

*Sage Action, Inc., Ithaca, N.Y.

The filling time (t_f) was found to be 0.82 seconds by taking photographs at various time intervals measured from initiation of deployment. The cameras taking the simultaneous photographs were synchronized by electronic time delay and each set to a 0.0117 ± 0.0005 second exposure time. This was done by photographing a moving fan blade. The fan's speed was predetermined by strobing.

Approximately twenty five pairs of photographs were taken at both T = 1 and in steady state ($T = \infty$). The bubble generating head was mounted at various radial locations in order to sufficiently cover the field. This resulted in roughly 250 matchable streaks for each of the two cases. Two typical photographs, both side views, are shown in Figures 3 and 4. Figure 3 shows the end of inflation which is still an unsteady flow condition, as may be seen by the whipping action of some of the suspension lines. The generating head was resting on the deployment tube. The Figure 4 photo is a steady state run. Here the generating head was approximately six inches from the centerline, and the generation rate was as high as was possible while still allowing discrimination and matching of individual bubble streaks in both top and side views.

Figure 3. Typical Streak Photograph (Side View) T=1

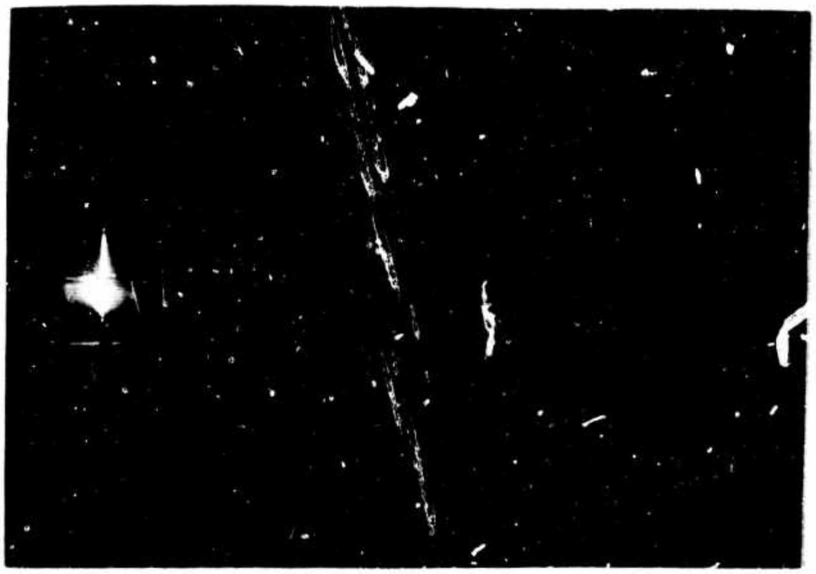


Figure 4. Typical Steady State Streak Photograph (Side View)

4. <u>Results</u>:

The basic results of the study are given in Figures 5 through 8. These map lines of constant nondimensional axial and radial velocity as functions of flowfield location. This information was obtained from each pair of photographs considering the fact that each camera had a conical field of view with a 72 inch altitude. Axial locations of each streak from top and side views usually agreed within 1/4 inch. Circumferential velocities were typically less than $\pm$ 0.5- 0.7 feet/second. Consequently, the velocities are considered to be functions of axial and radial location only. One of the salient points of contrast between the unsteady and steady flowfields are the relative dimensions of the turbulent regions. These regions are shown as being void of data. The large area of turbulence near the mouth previously seen by Lockman[2] in his pressure rake survey is certainly in evidence in the steady state data but nonexistent in the opening model. The wake sizes also differ. The average vent plane radius of the steady wake is roughly 1.15 times the projected radius of the canopy, while the corresponding value for the T = 1 case is 0.75. Secondly, it can be seen that the effects of the opening canopy are confined to regions relatively close to it, while those of the steadily operating parachute extend much further.

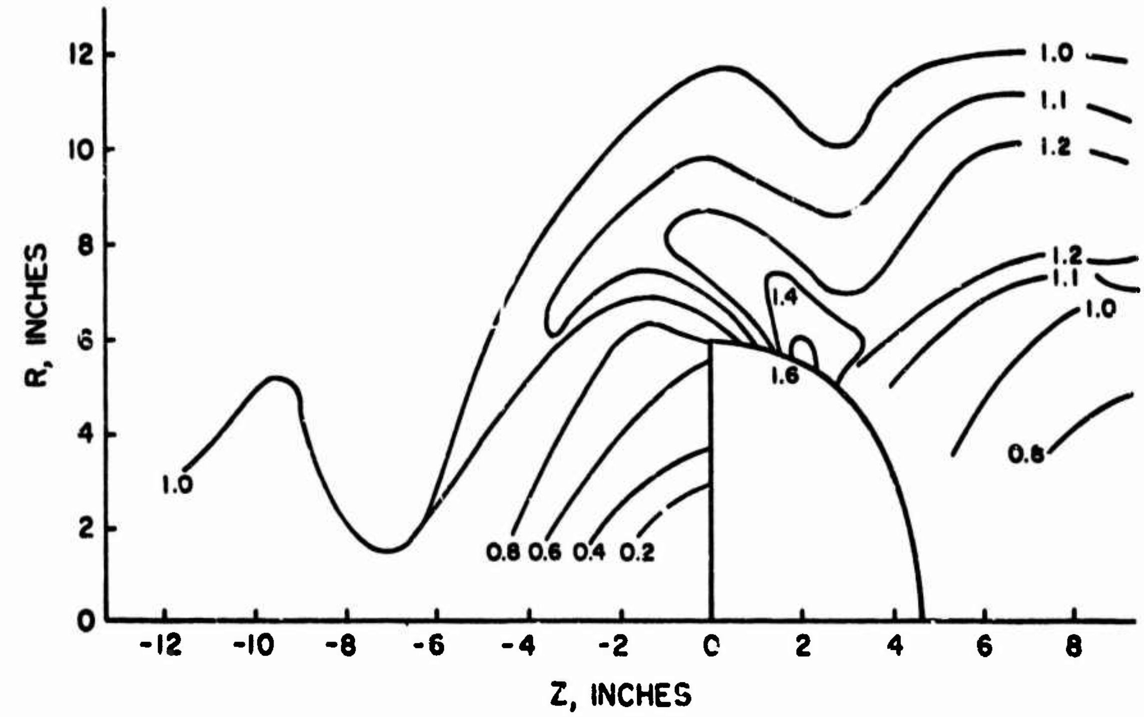


Figure 5. Contours of constant axial velocity ratio, V_z / V_∞, at T=1.

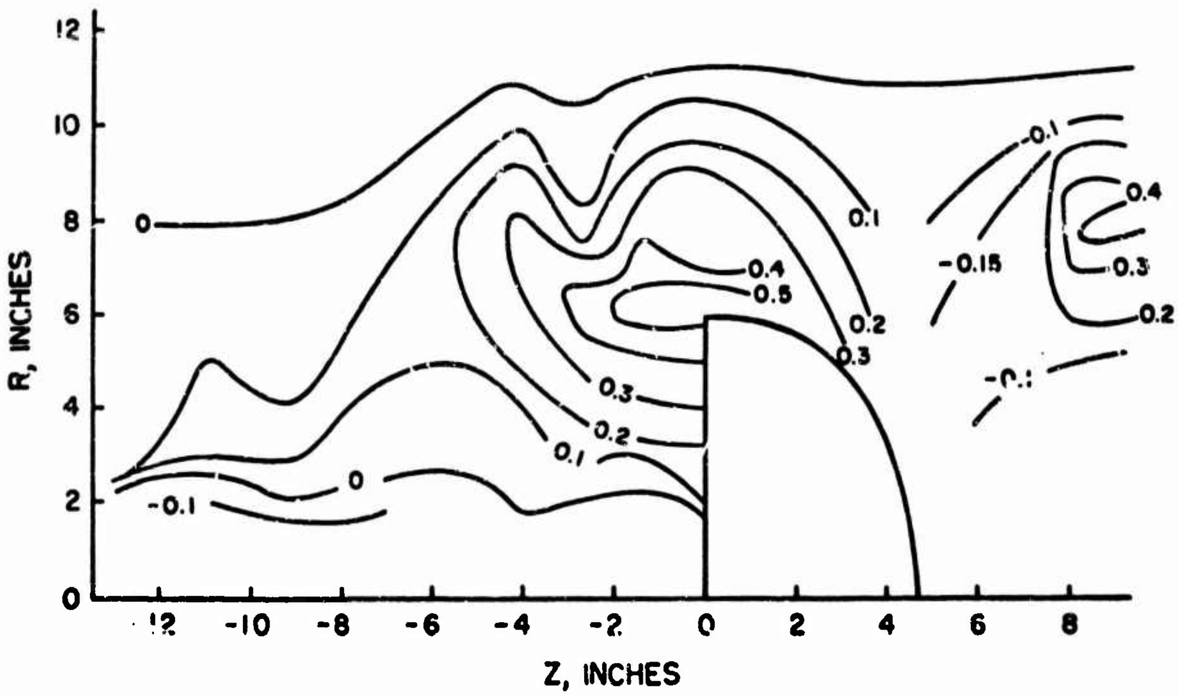


Figure 6. Contours of constant radial velocity ratio, V_r/ V_∞, at T = 1

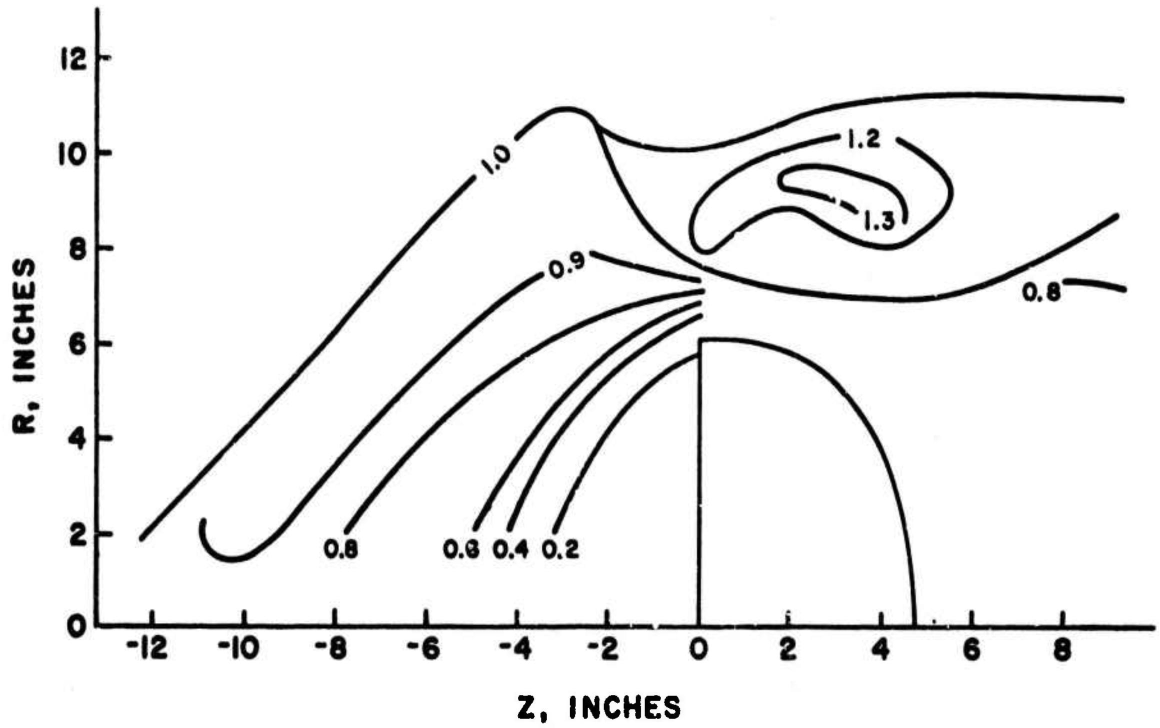


Figure 7. Contours of constant axial velocity ratio, V_z/V_∞, at T=∞

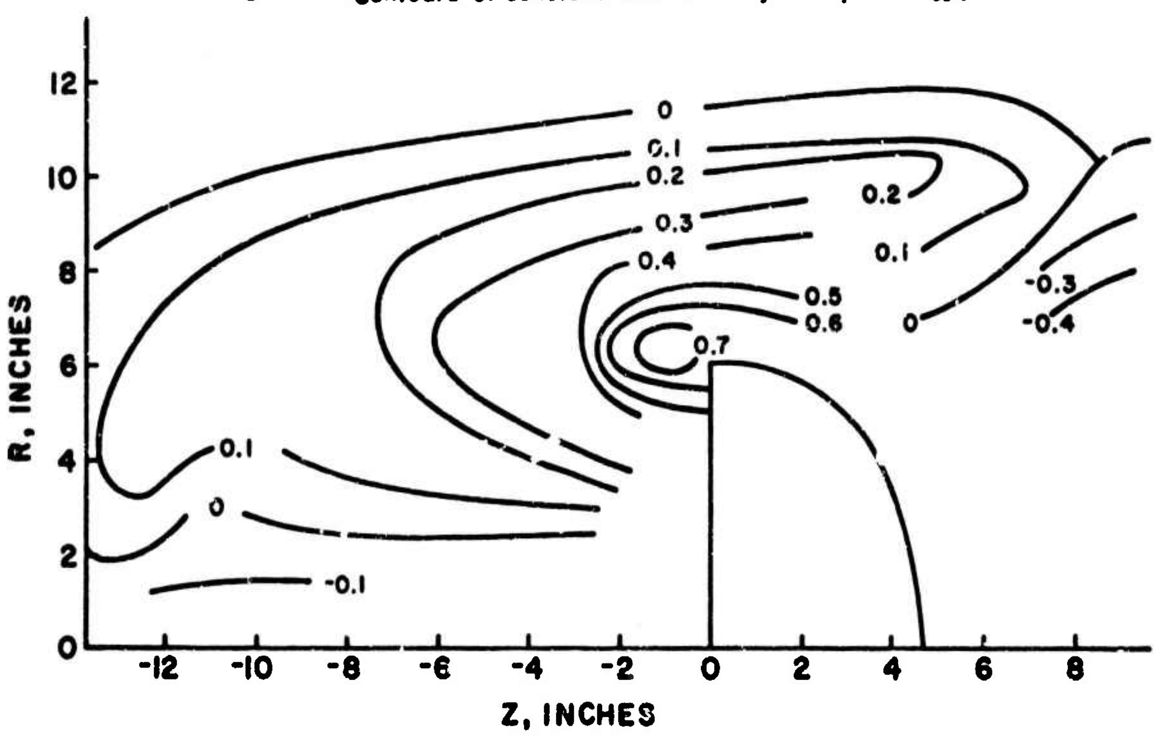


Figure 8. Contours of constant radial velocity ratio, V_r/V_∞ at T=∞

The lack of data over the first one or two inches of radius is due to the fact that the generating head could not be placed any closer to the centerline than 1 1/2 inches without obstructing the opening or being set into the parachute rigging lines. Generally, particles observed in the turbulent regions seemed to have no net velocity. Two of these may be seen downstream in Figure 4. In all fifty or so runs, only one particle was observed passing throug the vent. Finally, the aberrations seen between 10 and 14 inches upstream are due to the suspension lines and ring. Here, due to the relatively high density of 18 looped lines, there is an obstacle to the flow. Figure 9, a top view taken at an exposure time of 0.3 seconds, shows the bubbles moving to avoid the obstacle.

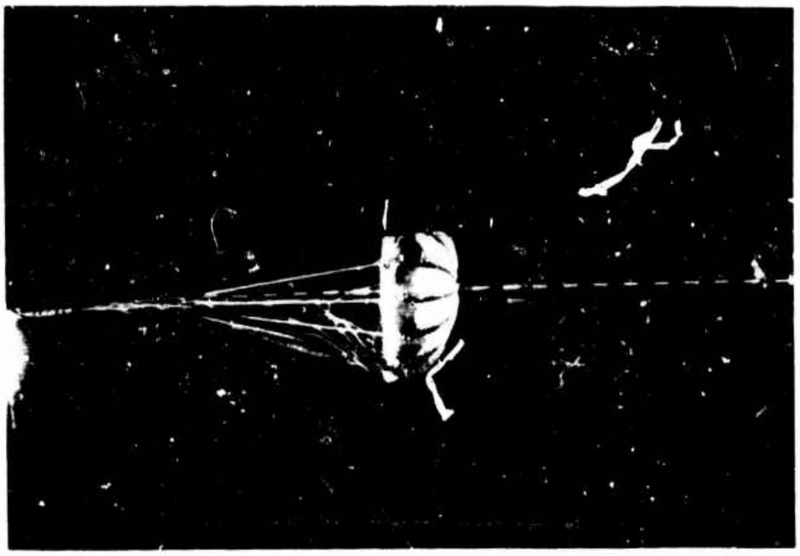


Figure 9. Top View Streak Photograph, Steady State, 0.3 Second Exposure Time

A few qualitative observations were made while actually viewing the steady state condition. In the regions of turbulence and those bordering them, the bubbles oscillate. This vibratory motion is superposed upon any other motion. This effect may be seen quite well in Figure 9, where both near the mouth and in the wake certain traces appear as two curved but parallel lines. The low velocities near the endpoints of the vibrating motion give a sufficiently long residence time to form a relatively intense image. The higher velocities at

mean locations between the lines give residence times which are too short to form an image. Motions characteristic of ring vortices parallel to the mouth plane and trailing vortices were also observed in the wake. The highly irregular nature of this flow would require considerably more data than that collected here to get any direct measurement of net average velocities in this region. A reasonable value could, however, be obtained by applying the conservation of mass to the region using the known velocity distributions in the non turbulent portions of the flow. Doing this here gives uncharted vent plane region velocities of $-0.49V_\infty$ and $+0.65V_\infty$ for the unsteady and steady cases, respectively. Considering the rapidly expanding canopy, the reverse flow in the unsteady case is not at all unreasonable. It is a well known fact that at T = 1 the canopy is being compressed in the axial direction. Calculation of a steady drag coefficient based upon nominal diameter, the average axial velocity of $0.65V_\infty$, no net radial velocity, and assuming that the vent plane pressure is freestream gives a $C_D = 0.70$. Since the actual vent plane pressure is below freestream, this underestimates the actual value. That the vent plane pressure is below freestream may be deduced from the changing radial velocities, which give a direction of the downstream path lines toward the centerline. Figure 10, a side view taken at 1/2 sec. exposure time, shows an example of this motion. Since the vent plane wake boundary has essentially the freestream value of velocity and Bernoulli's equation probably holds there, the pressure at that point would be close to freestream. This implies a lower value of pressure in the wake.

Figure 10. Side View Streak Photograph, Steady State, 0.5 Second Exposure Time

5. Conclusions and Recommendations:

The velocity profiles about a flat circular parachute model have been found for both a time late in the inflation process when the canopy shape is close to the steady state value and in steady state. The large differences between these two flows about geometrically similar bodies indicate that the idea of obtaining opening field data using a series of rigid models which represent various phases of the opening geometry is inaccurate. It also indicates that the extent of the flow which is turbulent during opening may be small enough so that a potential flow mathematical model could be used to give a reasonable description of the opening process.

The primary objective of this study was hampered by the lack of symmetry of the opening geometry. This could be corrected by either working in a vertical tunnel or combining increased illumination and faster film with increased tunnel speed or with an automatic camera and strobe light. Any future large scale survey should also incorporate an optical scanning computer input system. Even though a great deal of the data reduction was done by machine, the scheme used in this experiment was very tedious and time consuming.

This investigation demonstrated the ability of the helium bubble technique to collect previously unobtainable information. The difficulties encountered in this particular experiment appear to be readily solvable. Continuation studies are recommended since a great deal could be learned of parachute aerodynamics by use of this technique.

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